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WATER RESOURCES ACTIVITIES IN THE UNITED STATES

WATER RESOURCES RESEARCH NEEDS

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

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EIGHTY-SIXTH CONGRESS

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SELECT COMMITTEE ON NATIONAL WATER RESOURCES

(Pursuant to S. Res. 48, 86th Cong.)

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STATEMENT BY THE CHAIRMAN

FEBRUARY 5, 1960.

To the Members of the Senate Select Committee on National Water Resources:

At an early stage of the work of our committee under the provisions of Senate Resolution 48, we asked the Department of Agriculture for reports and projections of needs for the various programs carried out by the Department that are dependent upon water. As work on these progressed, it became increasingly clear that there would be no hope of meeting the Nation's needs in many of the fields involving agricultural uses of water unless improved methods and techniques of water use can continue to be developed. The Department of Agriculture has a great deal of research underway toward the end of developing such improvements. In order that the committee might have information on these important research programs and the Department's views as to what should be done in the field of research, I requested the Secretary of Agriculture to prepare a report for the committee covering research needs in the various fields of activity in the water resources field dealt with by agencies of the Department of Agriculture.

The report was prepared by a work group set up within the Department with membership from the several agencies engaged in the Department's research programs. The report points out in considerable detail the extent and character of research which will be needed if the best use of water is to be made in the production of essential agricultural and forest products.

Although the report deals primarily with research needs involved in the fields of agriculture and forestry, many of the programs deemed necessary have also been referred to in reports received from other agencies as being essential in their respective fields of water management and control. The report indicates that the need for basic meteorologic, climatologic, and hydrologic data is closely allied and vital to research and action programs for water resource development.

I believe the Department of Agriculture's views as to the need for research into many fields of water behavior will be of value to you, to other Members of the Senate, and to others interested in water problems, and therefore, I am having the report printed as one of our committee prints dealing with all aspects of water resources activities in the United States.

ROB'T S. KERR,
Chairman, Select Committee on
National Water Resources.

COMMUNICATIONS

August 26, 1959.

Hon. EZRA TAFT BENSON
The Secretary of Agriculture,
Department of Agriculture, Washington, D.C.

MY DEAR MR. SECRETARY: Further reference is made to my letter of June 15, relative to the work of the Select Committee on National Water Resources. Along with the information on its other activities in the water resources field, which the Department of Agriculture is preparing for the committee in response to our previous letters, information will be needed on research programs required in connection with future conservation, development, and use of water in the United States. It is understood that your Department has a work group which can handle this subject and it is hereby requested that a separate report be made to the committee on research needs in the water resources field.

Principal objective of the report on research should be to inform the committee as to the Nation's needs for research in the various fields of water resources development dealt with by the agencies of the Department of Agriculture, and the value of research in helping to assure that the Nation's water needs can be met in the future. The report should contain a summary and evaluation of present programs of research on water resources and the Department's suggestions for future research in this field. Attention should be given to those aspects of research needed to meet emerging local, regional, and national water problems, including institutional and economic research, as well as physical and biological research.

We would like this subject to be covered in a summary report of not more than 10,000 words with whatever tables, charts, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this report could be furnished the committee by November 1, 1959.

The committee staff will be glad to discuss any problems which may arise in the preparation of the report with representatives of the Department of Agriculture.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

DEPARTMENT OF AGRICULTURE,
Washington, D.C., February 3, 1960.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate.

DEAR SENATOR KERR: In response to your letter of August 26, 1959, the U.S. Department of Agriculture has made an analysis of the Nation's needs for water resources research of particular interest to agriculture.

The estimate of future water requirements which we have prepared for the select committee and submitted in separate reports are indicative of the need for increased emphasis on research to meet the problems of use and management of water resources in the future.

Research can contribute to meeting the Nation's future water needs by guiding development, management, and conservation of water, and by increasing the efficiency of water use. For example, we have estimated that for the year 2000 increased efficiency in storing, transporting, and using water could save millions of acre-feet annually. Accomplishing this would require comprehensive research, education, and technical assistance programs along with adjustments in water allocations. When we consider the competing demands for water in the future, research to provide basic knowledge of how to improve the efficiency of our water-management institutions and our individual water users becomes of paramount importance. Large benefits can also come from better watershed management, reducing sedimentation, and preventing flood damages.

In our report we have outlined needs for research on water resources for which the Department of Agriculture has responsibility. At the present time the Department's water-research activities are responsive to the demands for information to guide public water programs and private water users, but as we look forward to increasing stress upon our water resources, demands on these research programs will increase. The Department's programs will comtinue to be operated in cooperation with other Federal departments, State experiment stations, and other State and private agencies.

We shall be glad to be of any further assistance possible.

Sincerely yours,

ERVIN L. PETERSON, *Acting Secretary.*

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WATER RESOURCES RESEARCH NEEDS

Introduction

This report deals with research on the development, control, use, and allocation of water resources in agriculture. As Under Secretary True D. Morse stated in his letter July 13, 1959, to the select committee:

> In the production of food, fiber, and forest products water management is essential; first, as it falls upon the land and is used in place for the production of crops, range forage and forests, and, second, as it may be brought to use on the land through irrigation or controlled through drainage and flood prevention.

Proper water management encompasses the best use, control, and conservation of water that can be accomplished. The goal is the production of valuable agricultural and forest products making the best use of available water with a minimum waste of that water. Research will help attain that goal.

Within each region the total supply of water tends to be a fixed quantity. The demands of a growing population for this fixed quantity of water inevitably increase. Research offers the major opportunity for us to extend existing water supplies over these increased demands. Fortunately there are a number of research fields related to water that are, from the scientific standpoint, promising avenues toward increased efficiency of water use. Successful accomplishment of research goals in these fields can have a significant effect upon the future adequacy of our water resources. For example, the report on "Land and Water Potentials and Future Requirements" to the Senate select committee estimates that with increases in efficiency, the needed capacity for withdrawals of water for land now being irrigated can be reduced by approximately one-third of the amount now required to make full use of these lands.

Although many of these research fields are promising from the scientific standpoint, successful accomplishment of research goals in these fields is by no means assured. The programs outlined in " Facility Needs—Soil and Water Conservation Research" (4)[1] and in "Program for the National Forests," (15) present detailed information on facilities and research needs. Economic research on water problems must supply information needed for efficient and economic use of water.

This report stresses problems of national and regional nature but also provides a framework for many State and local studies. In addition to research on water resources conducted by State experiment stations and other State agencies, a significant amount of research is carried on by private institutions, agencies, and foundations. The Department of Agriculture in the past has cooperated with these groups and future research will be coordinated to the greatest extent possible with non-Federal efforts.

Vital to research and action programs for water resource development is the collection of basic meteorologic, climatologic, and hydrologic data. Data collection programs should be continued and expanded. It is important that accurate standard soil surveys be completed on all crop, forest, and range land of the country as rapidly as possible. Such programs should be closely integrated with research efforts so that basic data will be available and in form for best use for research.

Basic Research

Physical characteristics of water

Water is one of the most familiar substances in the world and this very familiarity has led scientists to direct their efforts to an understanding of things less common. Water has many unique physical and chemical properties that set it apart from other substances and make it suited for the important life processes.

Many of the difficulties in understanding the role and status of water in soils and plants stem from molecules of water tending to associate or polymerize with each other. Some leaders in

[1] Numbers in parentheses refer to publication listed at the end of the report.

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water research have stated that the molecular weight of water is governed by the size of the container holding it. Certain additives such as detergents and surfactants, present in water in very small amounts, cause marked changes in its properties. The tendency of water molecules to associate complicates the job of understanding its properties in soils because there is a gradual increase in the degree of disorder of water molecules as distance outward from the surfaces of the soil particles increases. Dissolved ions in the soil solution, temperature, hydrostatic pressure, and other variables, all affect the state of association of the water molecules. A better understanding of the properties of snow and ice could lead to better control of the rate of release of water from snowpacks.

Research results on the physical characteristics of water would be channeled to research groups working on the nature of water movement in soils and plants, hydraulics, and applied phases of water conservation. They might include new principles and techniques for studying the degree of association of water in complex systems, new ways of detecting energy changes in water, new additives that might cause beneficial changes in the physical structure of water, and other discoveries essential to breakthroughs in research on water in soils and plants.

Properties of water and water movement in soils

Understanding the movement of water through porous media is basic to an understanding of infiltration of water into soil, movement, storage and utilization of ground water, utilization of water by plants, and other important phases of the hydrologic cycle. The earth represents the most extensive and least costly "reservoir" for storage of available water. Full utilization of this reservoir cannot be made without better controls over the rate of movement of water into and through soils.

At the present time, adequate theory and techniques of measurement for predicting rate of water movement in soils exist for only a few situations. Thus, for a homogeneous soil having a stable structure, we can predict rate of water movement when soil is saturated with water under a constant hydraulic head. Even in this case, some of the measurements needed for this prediction are time consuming and lacking in desired accuracy. Where soil is only partially saturated with water—and this is the prevalent condition in the root zone of plants—the background of theory and measurement techniques needed for significant prediction of rate of water movement are less satisfactory. In particular, the effect of temperature gradients within soil upon the rate and direction of moisture movement in unsaturated soils is inadequately understood. Better understanding of this process might pave the way for development of techniques for increasing the efficiency of water storage in summer fallowed soils and in highly variable soils found in forested and grassland areas.

Research directed toward basic problems related to retention and movement of water in soils must provide a scientific background for a general research program in water conservation. Research should be directed toward such problems as the nature of the forces attracting water to different soils and the relative importance of different forces at different soil moisture contents. Other investigations should include studies of flow processes in soil water during infiltration of rain into the soil and during movement of water to plant roots. Methods of varying the attractive force of soils toward water need to be studied with special consideration to the possibility of developing soil treatments that might promote or restrict water movement. In the northern part of the country, studies are needed on soil freezing and thawing, the factors influencing the process, and the relationship of frozen soil to runoff, infiltration, and percolation.

Physical and chemical status of water in plants

Recently a special committee of the National Academy of Sciences-National Research Council identified the four most important needs concerning water as a factor in crop production. One of these four needs was stated as "the dynamics of water in plants."

In discussing needed research in this field, the NAS–NRC committee stated—

> The very core of the interconnected water phenomena of the soil-plant-atmosphere system is the physical state and dynamic behavior of water in living plants and plant parts. Research in this vital area is seriously hampered by the lack of measurement techniques for determining the free-energy status and flow characteristics of water in living plants under natural field conditions or experimentally induced environmental conditions. The development of suitable methods for such measurements would consti-

tute a major technique breakthrough in soil-plant-water research. Efforts directed toward this objective should be more vigorously encouraged and adequately supported (11).

The Department of Agriculture agrees with the NAS–NRC committee that research on water in plants is of critical importance.

Control over the process of movement of water from the soil through the plant to the atmosphere would be an important step in developing methods for improving water yield through vegetation management on watersheds, and to improvements in many other techniques for water conservation. Better understanding of the status of water within plants might provide a basis for the development of methods for transpiration control, and also might provide basic information essential to the development of drought-resistant plants through plant breeding programs.

The current research programs aimed directly at a better understanding of the status of water in plants are not extensive. Some work is underway in the Department, the State experiment stations, and private institutions.

Atmospheric phenomena

Water, in traveling through the hydrologic cycle, is subjected to many atmospheric forces and processes which tend to affect its movements to and from the land. Some of these are air temperature, solar energy, wind, and humidity. Research on weather modification is being supported by the National Science Foundation, but increased activity in this field is greatly needed for understanding agricultural and forest water problems (8). Until research produces further developments in weather modification, the vagaries of precipitation will prevail. However, there are many areas where even simple rainfall data are lacking.

Information on depth-area and depth-area-intensity relations of storms is available at only a few stations but is badly needed for developing formulas and prediction mechanisms for managing watersheds. The processes of deposition, sublimation, and melting of snow are not well understood; yet they are major considerations in many of our most critical water supplies.

Evaporation, one of the most important factors in water supply and water consumption, is largely controlled by air temperature, humidity, wind, and solar radiation. Basic data on these are very limited in many parts of the country; but needed even more is an improved understanding of their characteristics so that water losses from evaporation can be more readily controlled on mountain watersheds, agricultural lands, and storage reservoirs. Particularly in need of further study are the identification and magnitude of forces involved in solar radiation and the bearing of these forces on water use by plants and on the energy absorption rates of different kinds and arrangements of vegetation. This information is of value to those engaged in planning watershed developments and conservation projects as well as being basic to further research in watershed management.

There are weather stations at most of the experimental areas, but these are generally designed to furnish circumscribed data for other projects rather than being designed for studies of the atmospheric factors themselves. Some excellent studies of air temperature, humidity, and wind are being made in connection with forest fire research; but these do not relate to water movement in atmosphere, soils, and plants. Research in atmospheric phenomena bearing on water problems has been slow in developing because of a lack of research techniques and special instruments. New developments are badly needed. Futhermore, because of extreme fluctuations in climate year by year, some of these studies must be carried on for a relatively long time.

Hydraulics

Planning and design of all types of conservation, irrigation, and drainage measures and structures are dependent upon an understanding of the basic principles underlying the movement of water over and through the land surface, in the soil media, through natural channels and canals, through structures, and through closed conduits such as tile and pipelines. Water movement through the soil media is discussed above.

The objective of basic research in hydraulics is to discover or better define hydraulic principles and develop additional applications of these principles. Enactment of Public Law 83–566 and increased public interest in watershed protection measures and development and distribution of water supplies for both livestock and irrigation use offer expanded opportunities for the use of these findings.

Research can refine the techniques of streamflow measurement. Increased precision is necessary in determining hydraulic requirements of

structures for water conveyance or control and for watershed management studies. In many parts of the country accurate measurement of streamflow is extremely difficult and expensive because of steep stream gradients, sediment- or trash-laden flows, or inaccessible gaging sites. New flowmeters linked with telemetering devices for streamflow measurement are very much needed. Refinement of design criteria for irrigation structures will also be enhanced by improvements in methods for measuring flow in canals and ditches.

At present there is no concentrated research on the hydraulics of water movement over the land surface of watersheds. Overland flow and small channel flow is receiving attention on a laboratory and field basis in its application to border and furrow irrigation.

The research program should include analytical studies on the hydraulics of overland flow, the hydraulics of unsteady flow in the channel flow phase, the hydraulics of sediment ejectors and excluders for removing or eliminating sediments from canals and pipelines, hydraulics of supercritical flow structures especially where junctions are involved, hydraulics of flexible or lay-flat tubing, and the hydraulics of flow through conservation, irrigation, and drainage structures. In all cases laboratory and field facilities would be required for verification of developed principles. Improved instrumentation will be required for making adequate measurements of waterflow from natural watersheds and in canals. The report, "Facility Needs—Soil and Water Conservation Research" (4), describes the need for research centers for hydraulics and erosion research.

Erosion and sedimentation

Full understanding of fundamental erosion and sedimentation processes is a prerequisite for the planning and execution of sucessful programs for water resource development and utilization. Much has been learned from past investigations, but knowledge is still limited for the solution of many specific problems encountered in water resource development projects.

Within the Department of Agriculture, basic research on erosion and sedimentation is currently directed at isolating and evaluating the characteristics governing erodibility of various soils for determining the effects of rainfall, topography, crop cover, farming methods, and vegetative cover management practices upon the rates of erosion and sediment yield of watersheds; determining the processes creating streambank and gully erosion; investigating the mechanics of sediment entrainment and transportation; and computing quantities of sediment transported in natural and constructed channels. In this research program the capabilities and application of electronic computers, radio isotopes, and ultrasonics is being considered.

Basic research on the processes in these fields will help us understand their relation to, and effect upon, water resources. In addition there is need for a few well-equipped laboratories where erosional processes and sediment transport may be studied under carefully controlled conditions.

Legal-economic principles for water resources use

Growing competition among water uses increases the need for improved practices for evaluating, formulating, and selecting water resource development projects and for criteria and principles to guide modifications of the legal structure necessary for more efficient allocation of water resources.

The Department currently devotes some effort to research on basic legal and economic principles of water resource development and allocation. Some research on selected aspects of the evaluation problem has been undertaken at State and private universities and foundations. Basic research will provide means for alleviating conflicts between legal and economic bases for water allocation, as pointed out by the National Academy of Sciences Committee on Soil and Water Conservation (11).

To provide a more systematic and consistent framework for the evaluation of projects and programs, several difficult problems and controversial issues must be studied and clarified. These include the use of a social viewpoint in the selection and application of measurement standards and approaches; the treatment of taxes, risk, and interest in project evaluation and selection; the consideration to be given budget and other constraints in project analysis; the weight to be attached to secondary effects in measuring benefits and costs; the establishment of appropriate evaluation periods and amortization allowances; adaptations in standards and practices where local, regional, national, and international viewpoints are involved; the possibilities and limitations of

extending the coverage of monetary measurement to include additional types of project effects; and interrelationships between evaluation and cost-sharing aspects of resources programs.

A program of basic research on the legal framework for allocating water resources should involve four integrated phases: (*a*) The determination of the relationship between legal provisions and the use of water, drawing upon domestic and foreign experience; (*b*) the conceptual construction of alternative legal systems of allocating control of water; (*c*) the appraisal of the economic consequences of these alternative systems when tested in the physical-economic environment of the United States; and (*d*) the contrasting of the most efficient alternative against existing legal systems to identify those elements that might be modified to the economic benefit of the public.

Water Supply

Estimating water yields from upstream watersheds

Each year as the draft upon water resources increases, the potential water supply from upstream areas becomes more and more important. The rapid expansion in water use in recent years and the prospects for still greater demands in the future, emphasize the need for reliable information on water yields from upstream areas. Obviously, it is impossible to gage the flow of every upstream watershed, though each tributary watershed is an important component in the water supply picture. A reliable procedure for estimating water yields from ungaged streams is very much needed. Research will further identify and describe those climatic and watershed characteristics which affect water yield. Such research should encompass the relation between water yield and land use, cultural practices, and other means and measures employed in watershed protection programs, as well as those climatic, geologic, and physiographic factors which have a bearing upon streamflow or other disposition of precipitation.

Further research should be directed toward improving present methods of predicting the yield from snowmelt and developing improved automatic instrumentation for measuring factors affecting yields. A minimum of information on snowpack yields on small watersheds at low elevations is available and there is need to develop procedures for evaluating the snow water resource and predicting the amounts and regimen of flows to be expected.

Improved water yields

The limited research already done shows possibilities of higher water yields through improved management of vegetation. Further research is needed to develop principles, methods, and techniques for improving the amount, rate, timing, and quality of water yielded from watersheds. The opportunities for increasing water yields under different conditions of soils, climate, topography, and plant cover, cannot be assessed until more research is done, but it appears that possibilities are greatest in those areas of relatively high precipitation. However, research information for the drier zones could have great economic importance because even a small water yield increase may mean a considerable percentage difference in total yield. Some examples of practices offering promise toward increased yields are (*a*) converting to more efficient vegetative covers, (*b*) reducing the density of forest or brush cover to permit more precipitation to reach the ground and to reduce the number of plants using water, (*c*) cutting of forests in snowpack areas in special patterns to increase snow accumulation and control melt, and (*d*) influencing the drifting of snow by artificial means in high elevation areas to develop more late season streamflow. Analogous studies of the dependence of waterflow on the composition, density, and pattern of agricultural crops are equally important.

The demands for more water from watersheds are growing and the need to learn how to meet those demands is urgent. An expanded statement of research needs in vegetation management and water yields is given in the report by the Department of Agriculture to the Select Committee on National Water Resources in response to their letter of July 13, 1959.

Prevention of watershed damage

On the forested upstream watersheds, better understanding of the hydrologic and site productivity effects of different management practices is needed to provide the best integration of timber, forage, and crop production with minimum sediment damage. This will lead to development of improved methods and techniques for protecting, improving, and utilizing agricultural resources while maintaining stable soil, runoff, and

watershed conditions. Particularly critical and urgent is the need for development of new timber harvesting methods from steep forest areas. Methods of location and construction of access roads with minimum damage to streams and slopes is a closely related problem. There is also need for methods of managing recreation areas to prevent extreme soil compaction and watershed damage. Studies of range use intensity and management practices to minimize surface runoff, erosion, and harmful sedimentation should be expanded to include additional practices under various soil, climate, and forage conditions, with particular emphasis on high altitude ranges.

Research on both forested and agricultural watersheds should include increased emphasis on development of measures to prevent sheet, gully, and streambank erosion and consequent downstream sedimentation. Improvements on present procedures need to be developed to predict the sources, amount, and rate of sediment delivery from watersheds of varying sizes in the principal physiographic and climatic regions of the country.

Watershed rehabilitation

Watershed rehabilitation is important in stabilizing slopes and streambanks, in improving water quality coming from these areas, and in reducing peak runoff. Deteriorated watersheds require special management techniques involving protection from fire, grazing, and other disturbances; reforestation or range reseeding; use of soil conserving cover crops; and such measures as mulching, fertilizing, and mechanical practices and structures. Restorative measures are often difficult and costly. Current techniques should be evaluated under a wide variety of soil and climatic conditions, and new and more efficient techniques must be developed through research.

Ground water recharge

Ground water and the use of underground aquifers for storage has become important in the development of water resources in the United States. Ground water use more than doubled in the 10-year period following 1945. Because of the great increase in water use, rapidly declining water levels have been reported in a number of places. Declining water tables create a serious problem when pumping exceeds the rate of replenishment.

Studies are underway to develop criteria for characterizing sites as to their suitability to recharge, recharge by replenishment irrigation, the effects of recharge on ground water quality, the effect of silt-ladened water on recharge wells, and development of techniques for removal of sediments prior to recharging. An example of the diversion of industrial waste water is a case in New Jersey (6), where as much as 600 inches of water from a food-processing plant is sprayed into a forest area each year and is readily absorbed.

It is obvious that tremendous acreages in the West will depend upon the recharge of underground aquifers. The California water plan alone proposes some 10 to 12 million acre-feet of recharge annually. Techniques available today do not appear adequate for getting the water underground in the period of time necessary. It is not known if research can solve these problems. Some undoubtedly can be solved, but the rate and extent will depend upon the amount of creative effort directed toward their solution.

Research problems to be solved include: (*a*) Streambed percolation rates, (*b*) methods for handling sediments, (*c*) tools and techniques for characterizing recharge sites, (*d*) effects of prolonged recharge and pumping on ground water reservoirs, (*e*) the salt balance of ground water when using various qualities of water and recharging through overlying materials with varying salt contents, (*f*) the effects of replenishment irrigation on productive capacity of farmlands, (*g*) the development of techniques for using floodwaters that accumulate in low areas, and (*h*) the development of techniques for using ground water aquifers as part of the water storage needed in many river basins in the West.

The recharging of ground water supplies in watersheds is less direct and often more difficult to measure and to trace. More understanding is needed of the path taken by absorbed water from watersheds. Tracing and timing of underground water movement are needed to determine whether water becomes available for use elsewhere and how and when it reappears. Methods for carrying out such research are yet to be developed.

Water quality investigations

One of the most promising methods of extending our water supply is to make wider use of low quality water. The irrigation of cropland is potentially one of the most important ways of

using low quality water. The use of these waters must be guided by sound scientific principles to avoid permanent damage to the soil. These principles have not been fully established, although significant progress has been made.

The problem of use of low quality water has several facets. Perhaps the most universal one involves sediment resulting from erosion in the watershed. In the Western States, drainage waters from upstream irrigation projects return to the rivers and are available for downstream use becoming more saline with each use. Information on the exact limits of salinity and sodium absorption ratios for safe use of water on different soils and different plants is still incomplete. There is also a need for better information on the most efficient techniques and limits for blending high- and low-quality waters for different soils and crops, and on techniques for partial and selective desalinization of low-quality waters. These problems are becoming more severe with the expansion of irrigation further upstream along the western rivers, and with increased withdrawals of water for nonagricultural uses. Brackish water is available for irrigation use along many tidal inlets on the Atlantic Coast.

A further problem associated with water quality is concerned with the use of effluents of various types, especially those from food-processing plants. They contain organic and inorganic constituents that render their discharge into streams undesirable. The use of these effluents as irrigation water offers an economically attractive method for many processors, but technical information to guide this practice is meager. Until the effects of various effluents on different soils is better understood, their use must be limited. Several representatives of the canning industry urged additional research on this problem before the group appointed by the Secretary of Agriculture to study needs for soil and water research facilities.

In addition to the research efforts of the Department of Agriculture, other public agencies are accumulating inventory data on the quality of various waters. In view of the importance of the problem, further effort is essential.

Economics of watershed management

Improved methods for watershed program formulation are being developed in connection with the Public Law 566 program. Research is underway by the Department of Agriculture and some State experiment stations on the costs and returns of individual land treatment measures. Methodological studies in the adaption of mathematical programing and electronic computers to watershed planning are underway.

Research needs include the provision of improved input-output data required in watershed planning; determination of the value of water "in place" versus watershed yields; measurement of the benefits and costs of various types of control, stabilization, and rehabilitation measures; and determination of the effects on incidence of benefits and costs of alternative measures and programs.

Economics of ground water management

Problems in ground water use are manifest in rapidly increasing use, declining water tables, increasing costs of pumping, encroachment of inferior water, and conflicts with surface uses. Curtailment of use is but one solution. Others are more efficient use, better spacing of wells, artificial recharge, increased infiltration, reduced evapotranspiration, and balanced development of surface and ground water.

Land use studies by the Department and more recent investigations, primarily in California and Texas, have surveyed ground water uses and emerging problems. The Department is currently investigating economic problems of ground water development in connection with a study of land development under the Desert Land Act. Little research has been done on the economics of various alternatives for solving ground water problems. Some research on the economics of irrigation has application to ground water management.

Studies of costs and returns from pumping water for irrigation should be continued. Studies should be undertaken of legal devices and organizational arrangements needed to coordinate and regulate ground water use and to provide for financing and sharing costs of recharge structures. As data become available, studies should be made to determine economically optimum well spacings and pumping

rates and to measure costs and benefits in recharge projects.

Economics of new water technology

New water supplies are in the offing. The possibility of accurate long-range weather forecasting and weather modification raises a host of economic, legal, and administrative questions. As cost of demineralization of salt and brackish water is reduced, its potential for agricultural use increases. As the technology of water supply and use changes, research is needed to project the economic impacts of longrun supply changes, to point up necessary adjustments in farm and forest management, and to guide modifications in the legal and institutional framework.

The Department participates in research on the physical aspects of weather modification but has no economic research projects. Economically oriented studies have been conducted by several agricultural colleges, but these have either been very general or based on hypothetical rainfall increases. No research is underway on the economic impacts to agriculture of salt and brackish water utilization.

As attempts are made to control and modify weather, studies should be made of benefits and costs (including adverse effects) and the implications for legal and institutional changes needed to finance weather modification projects, reimburse the adversely affected, adjudicate rights to practice weather control, and distribute increases in water supplies.

Municipalities may be able to make use of nearby, but previously unusable, supplies and release for agricultural use water that is now, or might be, imported from distant areas. As costs of conversion come within the practical range, studies of possible reallocation of water could be made in selected areas.

As feasible methods are developed for reducing evapotranspiration, studies should be undertaken of costs and returns and design of economically optimal programs.

Water Use, Control, and Conservation

Control of water losses by evaporation

Sixty to seventy percent of the Nation's total precipitation returns to the atmosphere through evapotranspiration. Evaporation from soil, snow, and water accounts for a very significant portion of this consumption, probably between 40 and 50 percent. Reduction of these losses would be a big step toward extending available water supplies to productive uses.

Basic research is needed on the evaporation process in relation to the properties of soil, water, snow, and plants as a basis for development of control practices.

Numerous approaches to evaporation control need thorough study. Alteration of soil, water, vegetative, or snow surfaces to modify solar energy absorption, heat exchange with the atmosphere, wind movement, temperature, and humidity is one approach. Soil conditions might be altered to prevent moisture from moving to the soil surface where it can evaporate. Evaporative surfaces might be treated to reduce vapor exchange with the atmosphere. Underground rather than surface storage of fresh waters, alteration of reservoir design or reservoir environment, and concentration of water from small showers by waterproofing a portion of the land area, thereby reducing the evaporative surface, need extensive study, particularly in drier areas. Practices such as alteration of vegetative complexes, reduction of leaf area, chemical treatment of plant surfaces, and modification of land use also have possibilities for evaporation reduction.

There is great potential for more efficient use of moisture supplies. "Facility Needs—Soil and Water Conservation Research" (4) and "Program for the National Forests" (15) outline the kind of facilities which could help in the solution of this problem. Reduction of evaporation losses not only would mean that crops could be grown in areas now too dry, but should greatly improve the moisture environment on all agricultural lands and provide appreciable increases to present surface water supplies.

Plant management for efficient water use

About 25 percent of all precipitation is transpired by plants. Opportunities exist for increasing water use efficiency by cultural and management practices; by development of new varieties that produce an equivalent crop while transpiring less; by application of chemical or mechanical treatments to plants to reduce water use; and by altering the geometry and sequence of crops in field plantings and forest stands.

Fertility management and adjustment

Research by State, Federal, and private agencies has shown that water use efficiency by crop and range plants can sometimes be increased twofold to threefold if all essential nutrients are adequately supplied. Because of variations in available moisture, precipitation, irrigation water supply, and climate, the problem of predicting the nutrient supplying power of the soil and the additional fertilizer needed for maximum water use efficiency is unsolved.

Some of the research done so far points to the possibility of significant savings of irrigation water through improved soil fertility practices. The major savings would come from presently irrigated marginal land.

Current research is principally of the applied type and is carried out in scattered locations. Further research is necessary to more fully understand the fundamental relationships of soil moisture supply and nutrient use to growth, survival, and production of crop and range plants.

Tillage for efficient water use

Water intake, transmission, and storage, as well as losses by evaporation and use by crops, are altered in a major way by tillage. Tillage for weed control is directly related to the efficient use of water since weeds use significant amounts of water.

Studies are needed of the effects of tillage on soil properties important in water intake, movement, storage, evaporation, and penetration of plant roots. Minimum tillage, deep plowing, chiseling, vertical mulching, and other practices should be evaluated and improved.

Control of seepage

Water lost from seepage has been estimated to be from 25 to 40 percent of all water diverted from streams. Even taking the lower value of 25 percent, the water lost from the 46 U. S. Bureau of Reclamation projects in 1949 would amount to 3.9 million acre-feet. Some of this is reused. Seepage on other projects is probably larger because of less rigid construction specifications and less operating control. There are other problems where seepage losses occur. Special drains need to be built. Conveyance channels must be larger to carry water demand plus seepage. Banks and adjacent roadbeds are softened creating safety hazards. Valuable cropland is damaged by seepage and accumulation of salts. Losses in farm ditches are as high as 20 percent per 1,000 feet of ditch in sandy soils. Losses from temporary storage structures for irrigation water are also high in sandy soils. Reduction of seepage would help meet future water needs for domestic, industrial, and irrigation use. Adequate information is needed to determine that portion currently lost to beneficial use.

Current Department of Agriculture research is directed toward evaluating the effectiveness of means for controlling seepage losses from both small storage and conveyance structures. Techniques are being developed for installing new materials where they are most applicable.

Because no inexpensive method is available, seepage control is a major problem with most irrigation projects. Therefore, development of new methods and materials for economic seepage control is needed to meet future demands for water. Better methods of measuring seepage are also needed.

Control of phreatophytes

Phreatophytes (plants whose roots extend into the underground water table or the capillary fringe above it) occupy 16 million acres of land in Western United States. Where phreatophyte growth is abundant, two principal problems are created in addition to water waste: (*a*) Reduced economic use of lands and (*b*) increased flood hazards.

Improved understanding of the interrelationships of these plants with their surroundings is needed. Such an understanding will help guide further research in chemical, mechanical, and ecological control treatments that may be more effective and economic than present treatments. Some studies of saltcedar are already underway.

Much more knowledge of control techniques must be obtained before action programs can be improved; but an equally important prerequisite to action programs is the development of information on methods, techniques, and species to use for replacement of phreatophytes. If this step is not taken, an even less desirable kind of vegetation may invade the site or severe erosion may occur.

It is necessary to learn how much water different phreatophytes consume and when. This requires studies of water table levels, streamflow fluctuations, and evapotranspiration rates of individual plant species under various soils and climates.

To complete the picture, the water consuming and ecological characteristics of the replacement vegetation also need to be studied.

New research on reducing riparian woodland vegetation is starting in southern California, and plans are being drawn for further work of this kind on several municipal watersheds in the Northeast. Analysis of the problem indicates research should be conducted on various control measures and factors affecting spread, survival, and methods of establishing more desirable vegetation and the development of soil and water management methods for maintaining replacement vegetation and prevention of erosion.

Irrigation

The greatest single use of fresh water in the United States is for irrigation. With the rapid increase in use of water for industrial and domestic purposes, competition for irrigation water is becoming more and more acute. Furthermore, potential development of water supplies is rapidly approaching the limits of this resource in many areas. Decreasing wasteful use of water in irrigated projects can make more water available to presently irrigated lands and for development of new areas. Unsolved problems include (*a*) the control of water losses in storage and transport, including seepage and water use by nonbeneficial vegetation; (*b*) improved efficiency of water application and distribution; (*c*) improved water application control structures and measuring devices; (*d*) proper timing of irrigation for efficient water use and drainage control; and (*e*) better understanding of basic soil-water-plant relationships needed for more efficient utilization of water by plants. "Soil and Water Problems and Research Needs for the West" (2) and "Facility Needs—Soil and Water Conservation Research" (4) describe an irrigation research center and provide detailed information related to the problems and research needs of irrigation agriculture.

Wetland management

There are many areas where agricultural production is imperiled and rendered inefficient because of periods of excess water. In addition, an estimated 35 million acres of wetlands, mostly forested, appear to offer opportunities for increased production of farm, forest, or wildlife crops through the development and application of modified drainage practices and other management techniques. The effect of alternative types of drainage upon ground water levels, flood runoff, and seasonal streamflow patterns present problems for solution. The value of water in swamps as sources of underground water recharge or as a stabilizing influence on streamflow should be determined.

The vegetational responses to controlled drainage, including productivity of the site for tree growth and suitability for reproduction, changes in plant competition, and in fuel accumulation and fire hazard can be understood through research. There is a particular need for knowing at what level the water table should be maintained at different seasons of the year for optimum plant establishment and growth on the different soils. Some wetlands have high value as habitat for fish and game and considerable potential as recreational sites. Furthermore, they could serve as supplemental sources of water for industry. Conflicts of use are bound to arise and research that will build up a fund of facts upon which decisions can be based should be undertaken at once.

The economy of many agricultural areas is based upon the continuing success of farm drainage systems, and will be jeopardized by a failure of these systems through soil changes. A number of drainage and water control projects have already been started on forest lands, particularly in the Southeast.

The amount of drainage research presently being done is small.

Control of floodwater damage

The activity under the Watershed Protection and Flood Prevention Act as well as other upstream programs requires a detailed knowledge of frequency and magnitude of floodflows and floodwater damage in upstream areas.

Hydrologic information is needed for: (*a*) The design of upstream water use and control structures and (*b*) the evaluation of flood damage and planning of upstream watershed improvement programs. In engineering design work this information is used for determining the efficient, safe, or economic capacity of reservoirs and spillways of dams for waterflow retardation and municipal, industrial, irrigation, and stock water use. It is also needed for design of culvert and bridge open-

ings; desilting and debris basins; artificial channels, including water disposal systems, diversion ditches, farm waterways and floodways; and for the hydraulic features of grade stabilization and gully control structures.

It is also used in determining the economic feasibility of watershed programs and individual water use and control structures. This requires reliable estimates of flows for the condition without the program and for conditions as they will be after the program is installed. The Department of Agriculture over the past 30 years has made runoff and related measurements on about 350 small agricultural watersheds, many of which are less than 10 acres in size. Although these provided the basic information by which design procedures could be developed for small onfarm structures and measures, much more information is needed to develop procedures for predicting flows from the 50-acre to 400-square mile watersheds. The purpose of this research is to compile information and develop procedures for predicting such flows from readily available climatic data and watershed characteristics.

Measurement of floodwater damages

Development of work plans under authority of Public Law 566 (amended) as well as other programs to reduce flooding requires an evaluation of floodwater damages to crops. Estimates were developed by the Department in the early 1940's of the relationships between duration and depth of inundation during various periods of the growing season and the degree of damage to various agricultural crops. The important elements in this method are the "factors of damage."

Accurate and detailed factors of damage for each agricultural crop grown on lands subject to flooding and for each stage of crop development must be determined. These factors are used in the formulation and economic evaluation of projects; and their development must be integrated with the research outlined in the section on economics of flood prevention.

Water and snow control structures

Applied research could evaluate the hydraulic performance of existing and improved types of conservation, irrigation, and drainage structures. Performance needs to be evaluated in terms of onsite conditions. Need for this information emanates from an increasing demand for watershed protection measures and irrigation and drainage systems.

Current research is evaluating hydraulic performance of straight-drop spillways, various types of inlets to closed conduit spillways, existing and proposed cantilevered outlets, transitions from circular to rectangular flow cross sections, and trash guards for closed conduit spillway entrances. Investigations are continuing on the performance of irrigation distribution systems with respect to alleviating seepage losses due to unlined canals and reducing expensive clearing and maintenance due to poorly designed drops, turnouts, and other control structures. Similar work is carried on by State colleges, universities, and other State and Federal agencies.

In meeting research needs in this field, additional attention must be given to improving closed conduit spillways and other conservation structures and developing suitable trash guards, stilling basins, and other means of dissipating energy. Research can provide information on reducing maintenance expenses of irrigation systems, reducing labor requirements, developing combined turnout and accurate measuring devices, and developing improved and automatic facilities for uniform application of irrigation water. Improved drainage structures will require an understanding of existing tile line performance, criteria for use of filters, and adaptation of low-cost materials.

Another important group of structures on which location, design, and performance research is needed are those for snow control. At high elevations in the mountains of the West snow accumulates to great depths in the lee of natural barriers. These deep drifts are sources of late season streamflow and are important in areas of short summer water supplies. The development of structures for creating artificial barriers for snow accumulation could add considerably to late season melt. Snow accumulations on precarious slopes and ridges may present real dangers from snow slides and avalanches; and structures to break up such slides before they reach winter sports areas, roads,

or other properties are needed. The need for avalanche control is increasing rapidly as winter use of mountainous areas increases.

Soil mechanics

In many parts of the Nation, complex problems exist in stabilization of dams and dikes for the small watershed program and of banks for irrigation canals, storage reservoirs, and drain ditches.

Methods, materials, and procedures for treating unstable and porous soils during and after construction to control seepage and stabilize soil for extensive periods should be developed and evaluated through research. Development of improved bank stabilization materials such as oil plasticizers and cements with the necessary installation or application procedures will greatly reduce maintenance costs and reduce damage to irrigation and drainage systems. Seepage also can be reduced considerably by such treatment. Adequate progress in improving existing techniques and developing improved materials and methods for bank stabilization and seepage control will require an expanded program along with necessary facilities and equipment.

Economics of irrigation

Research on costs and returns of irrigation has been carried out, or is underway, in many States, either by State experiment stations or by USDA personnel. Aside from studies evaluating proposed irrigation projects by the Bureau of Reclamation and the Department of Agriculture, most of this work has been oriented to individual farms. An analysis of transfers of shares and sale of water within and between irrigation companies is being made in Colorado to determine ranges of water values and factors affecting value.

Research should be expanded on the costs and returns from irrigation in various regions of the country for different crops and soil conditions and taking account of drought probabilities and the interaction of water with other production factors. Input-output data obtained by these studies should be analyzed and additional studies made to obtain reliable estimates of the marginal productivities of water in irrigation under different conditions and to develop demand schedules for irrigation water. These could then be compared with demand for other uses and aid in the allocation of scarce water supplies and the determination of optimum scale of irrigation works.

Economics of flood prevention

All areas of the United States are affected, directly or indirectly, by floods. Determining the economic effects from floods of varying volumes, durations, and rates of flow and costs of alternative flood damage reduction measures must be made for a range of conditions. The incidence of benefits and damages must be traced and appraisals made of the economic effects of flood prevention upon the economy. From these data, benefit-cost relationships may be constructed as needed.

Studies of the economics of flood prevention are largely confined to evaluations of specific projects. Efforts are being made to devise improved procedures for obtaining estimates of flood damage and of land enhancement from reduced flooding. Methods of measuring the economic results of installed watershed programs are being developed. Studies of land development are being made in connection with flood prevention and drainage programs and of the economics of stream stabilization. The Department has a small contract with the University of Chicago for a pilot study of the factors affecting use of rural flood plains.

Research should supply data essential to river basin and watershed development programs and determine soil and agronomic effects and resultant economic values for varying degrees and types of inundation. Flood damage analysis work would be made more effective by the development of schedules of costs of various degrees of flood prevention by type of structure and by area. Project formulation procedures should be developed that will permit adjustments in use of flood plains to be considered as an alternative or adjunct to structural measures. Future research should also provide in readily available form estimates of the degree of damage to be expected from floods of various sizes classified by area and type of development involved. Prearranged surveys should be established for obtaining and processing data on damages and other characteristics of floods as they occur.

Economics of drainage

Research should ascertain types and areas where drainage of land for agricultural production will be economically feasible. The economics of alternative uses of poorly drained land for tilling,

grazing, or forestry, particularly in the eastern regions should be considered. Alternative possibilities of obtaining projected requirements for agricultural products need to be compared with the costs of obtaining additional production through drainage. Costs, methods, and returns from draining land for crops and pasture are needed, applicable to individual farms as well as for group or area efforts. Alternative organizational approaches should be evaluated from the standpoint of obtaining the most efficient construction and maintenance of group drainage works.

An economic appraisal of drainage for crop and pasture production is underway on a limited scale in the Department. This study has a major objective of appraising the economics of potential development of land through drainage. Methods, costs, and returns are being studied in selected areas where drainage works are being established on a significant scale. A study is also underway on the economics of land forming for water management.

Future research should include studies of the physical and monetary returns from installing and maintaining drainage for selected benchmark soils under different levels of management. These studies should reveal the influence of drain type, spacing, and size on expected returns. Further appraisal of the costs and benefits of supplemental drainage including the practice of land forming should be a part of a research program dealing with draining land for agricultural uses. Agricultural uses of wetlands should also be studied in relation to the use of such lands for water storage and wildlife habitat and the multiple use of such lands. Drainage of marsh and tidal lands needs special attention, as pumping of drainage water is often required and special soil treatment problems are encountered.

Multiple-Purpose Water Management

Legal and organizational arrangements

Much of the law affecting water rights is not in the law books but contained in case law. An inventory of the State and local agencies having authorities in this field would be useful. Research should include the compilation, analysis, and comparison between States of the case and statutory law affecting the water resource, investigations of their operation, and evaluation in the light of developed principles and criteria. Such studies would guide public agencies and legislative bodies by providing information on the economic consequences of proposed action.

The Department has studies underway analyzing and comparing State water-right laws and analyzing their relationships to economic and physical factors. Some of these studies also deal with relevant interstate, Federal, and international matters. Similar or related studies have been, or are being, conducted by study committees, universities, foundations, and other agencies in a number of States. The Department has a study underway analyzing local organizational arrangements for small watershed projects.

Research efforts should be continued and the following studies initiated: (*a*) Additional studies of the actual administration and operation of State water-right laws; (*b*) more extensive analyses of relationships between water rights and organized watershed development and management; (*c*) analyses of water-rights problems in expanding uses of water for recreational purposes; (*d*) a comparative analysis of water rights throughout the United States; and (*e*) an analysis of responsibilities, authorities, and activities of local districts and their relation to State and Federal agencies in the field of water resource control, development, and allocation.

Multiple-purpose project planning

The feasibility of water development and control for agriculture can best be determined by planning some water projects on a multiple-purpose basis, whereby such project functions as irrigation, drainage, stockwater development, and agricultural flood control are coordinated with nonagricultural functions in formulating water programs. The legal and organizational aspects of multiple-purpose water management also bear on economic feasibility.

Given a conceptual framework, many problems of procedure and measurement remain. Considerable progress is being made in adapting mathematical programing and electronic computers to problems of multiple-purpose water planning, a

development that should greatly broaden the range of alternative programs given detailed study.

Major research problems in determining the role of agricultural development in multiple-purpose water management are: (*a*) Greater efforts toward identifying and measuring the economic and social effects of competing water project functions; (*b*) the development of more effective planning procedures, especially those that adequately recognize any available alternatives; (*c*) the development of more reliable estimates of future land uses and demands and prices for project goods and services; (*d*) project planning and scheduling in relation to budgetry limitations; (*e*) development of procedures for incorporating sufficient flexibility in projects and plans to permit adjustments to meet changing conditions; and (*f*) development of fundamental data and relationships and procedures for making useful projections of future water requirements and potentials.

Value of water in competing uses

Determining water value is one necessary element in the study of efficient allocation of water resources. Closely related are competitive relationships between water uses, the economic limits of developing supplies, and analysis of forces determining patterns of water use.

Extensive work has been done on the economic returns from irrigation uses in specific situations. Little has been done to study the value of agricultural and other uses of water in various regions in terms of efficient alternatives of meeting future national requirements of food, fiber, and other products.

Studies of the value of agricultural uses of water should be integrated more closely with similar studies of other uses, and accompanied by research designed to establish criteria for comparing values of uses in agriculture with other uses. An attempt should be made to orient such research toward the efficiency of alternate ways of meeting national needs. This research should be broadened to include study of the competitive relationships in terms of points and time of use, return flows, and water quality.

Benefit-cost incidence and cost-sharing arrangements

Significant variations exist in the incidence of benefits and of costs under prevailing cost-sharing requirements. Under some water resource programs beneficiaries bear substantial costs; under others practically none. Requirements also vary for similar programs administered by different governmental agencies. The absence of consistent practices contributes to ineffective resource use and inequitable patterns of net benefit distribution.

Some attention is being given the general problem by the Evaluation Standards Subcommittee of the Interagency Committee on Water Resources. Incidental attention has been given benefit and cost incidence and cost-sharing problems as phases of economic evaluation studies.

A study for which there is urgent need involves the development of a systematic and comprehensive conceptual analysis of all incidence aspects of water resource development projects, including the assignment of financial responsibility to various levels of government, regions, areas, groups, and individuals; the compensation required for adverse impacts; the ways in which cost-sharing requirements may be used to modify incidence and promote program and policy objectives; and the possibilities and limitations of alternative means of controlling incidence.

In addition, empirical studies should be made of such aspects as the relation of cost sharing to project evaluation and use of project services; the merits and disadvantages of alternative approaches for apportioning charges and assessments; appropriate bases for compensation; relation of cost sharing to area and regional economic development, accrual of windfall gains, economic stability, benefit dispersal patterns, and resource allocation; identification of beneficiaries and measurement of their benefits; and mechanisms for the assessment and collection of charges.

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